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TIME-OPTIMAL SOLAR SAIL HETEROCLINIC CONNECTIONS FOR AN EARTH-MARS CYCLER

Abstract

Research in the field of solar sailing is flourishing after recent successes such as JAXA's IKAROS mission, NASA's NanoSail-D2 mission and The Planetary Society's LightSail-1 mission. Solar sails exploit the radiation pressure generated by solar photons reflecting off a large, highly reflective membrane to produce continuous thrust. As a propellant-less form of propulsion, they have in principle unlimited ΔV at their disposal, which enables high-energy and long-duration missions. As an example, in this paper, solar sails are exploited to create an Earth-Mars cycler between libration point orbits at the Earth-Moon L_2 point and the Sun-Mars L_1 point. The former is selected as it is considered an attractive location for a future space station as departure location to interplanetary destinations.

In order to facilitate as many cycler roundtrips as possible, the overall objective of this paper is to minimize the time of flight, which requires the solution to an optimal control problem. This solution is obtained using a direct pseudospectral method and exploiting techniques from dynamical systems theory to obtain an initial guess. In particular, connections between the unstable and stable manifolds of the target libration point orbits at the Earth-Moon L_2 point and the Sun-Mars L_1 point are sought for. While such connections do not exist in the ballistic case, they can be achieved by complementing the dynamics with a solar sail and assuming a constant attitude of the sail with respect to the incoming solar radiation. These trajectories are then sub-optimal due to the assumed constant sail attitude as well as minor discontinuities in position and velocity at the linkage of the manifolds, which are overcome by transferring the initial guess to the optimal control solver.

For near- to mid-term sails, preliminary results show time-optimal round-trip trajectories that span three synodic Earth-Mars periods, with six months to one year stay times at the libration point orbits. These results are obtained by designing the out- and inbound trajectories separately, while the final paper will also consider a full end-to-end mission optimization. Through the use of solar sailing the resulting Mars cyclers can, in theory, be maintained indefinitely, enabling a continuous cargo gateway between Earth and Mars for future human exploration of Mars.